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(54) **Titre** : METHODE ET DISPOSITIF SERVANT A REDUIRE LA POUDRE DE FER PAR REDUCTION
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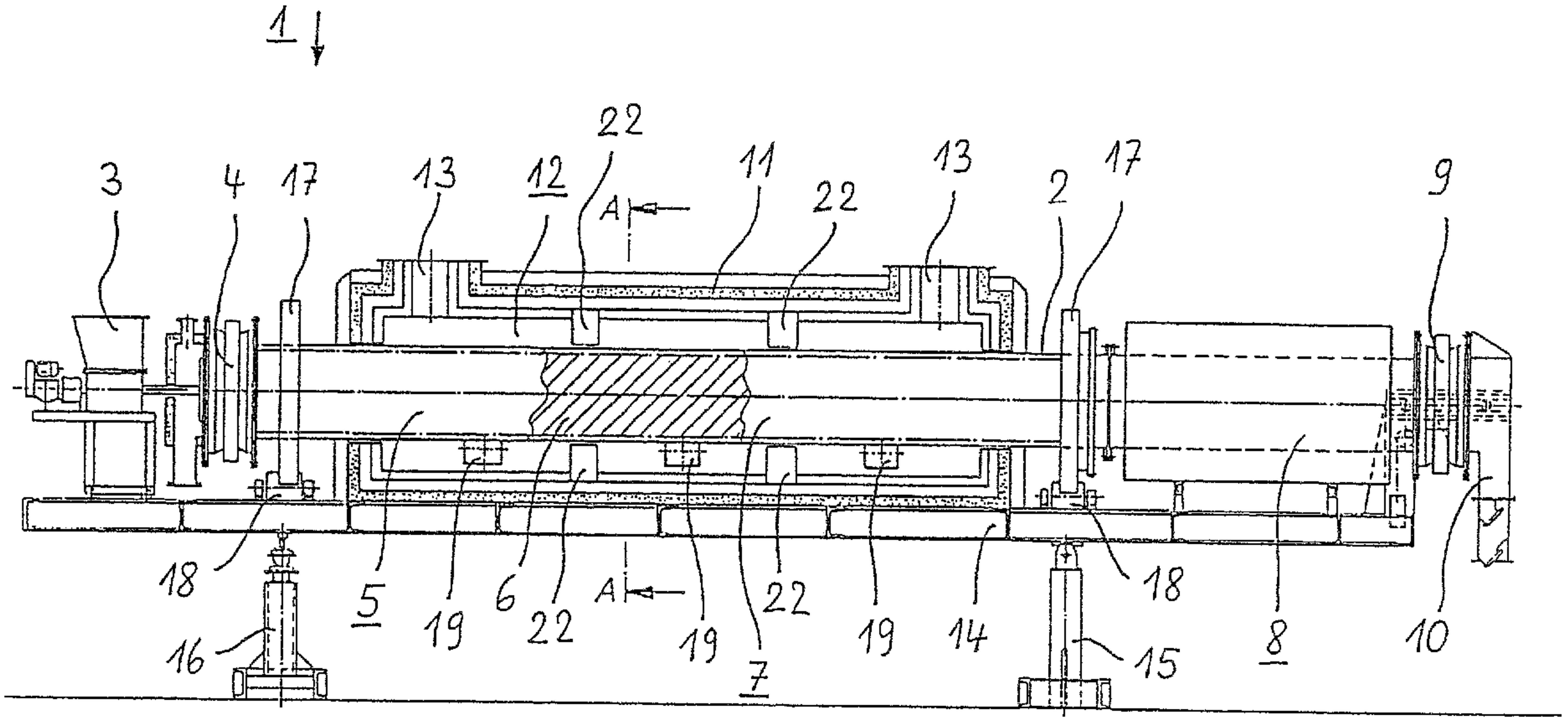

(57) **Abrégé/Abstract**:
The present invention relates to a process for the continuous reduction and soft annealing of water-atomized iron powder that is passed through an indirectly heated processing chamber with a heating, reduction, and cooling zone, in the form of a loose powder charge. In order to increase the throughput and achieve reduced energy and reduction agent costs, it is proposed that the powder charge be agitated at least in the reduction zone when passing through the processing chamber during constant mixing, when the temperature amounts to 800 to 950°C, and in that fresh reduction gas be constantly introduced into the reduction zone in order to regulate the dewpoint of the furnace atmosphere.

ABSTRACT

The present invention relates to a process for the continuous reduction and soft annealing of water-atomized iron powder that is passed through an indirectly heated processing chamber with a heating, reduction, and cooling zone, in the form of a loose powder charge. In order to increase the throughput and achieve reduced energy and reduction agent costs, it is proposed that the powder charge be agitated at least in the reduction zone when passing through the processing chamber during constant mixing, when the temperature amounts to 800 to 950°C, and in that fresh reduction gas be constantly introduced into the reduction zone in order to regulate the dewpoint of the furnace atmosphere.

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A PROCESS AND AN APPARATUS FOR REDUCTION ANNEALING IRON POWDER

The present invention relates to a process for the reduction annealing of iron powder that has been formed by the water atomization of molten iron, as described herein, and an apparatus for carrying out this process.

It is known that molten iron can be atomized into very small particles with the help of jets of gas or water that are directed onto a flow of molten material under high pressure so that a finely divided iron powder is formed as a result of the rapid cooling of the particles of molten material that takes place when this is done. Because of the fact that the atomizing medium that is used (e.g., water) is not free of oxygen and the atomization is not effected in an inert atmosphere, an oxide covering is formed on the individual particles of iron, and this poses an obstacle to subsequent processing of the iron powder, e.g., as it is used in sintering metallurgy. In addition, an increase in hardness of the iron particles, which takes place because of the extremely rapid cooling despite its low carbon content, is a further obstacle to processing as may be required for a number of applications.

In order to eliminate these obstacles, it is customary (e.g., as described in DE 37 22 956 C1) to subject the oxidized iron powder that is obtained from this atomization of molten material to annealing in a reducing atmosphere. To this end, continuous furnaces such as, for example, belt furnaces (cf. US 4 448 746), walking beam furnaces, or rolling hearth furnaces are used. When this is done, the iron powder is piled in bulk on a dish-like base in the annealing furnace at temperatures of 900 to 1,200°C (in the heated furnace casing), as a rule at temperatures in excess of 950°C. In most instances, a furnace atmosphere that has been enriched with hydrogen is used for the reduction. DE 37 22 956 C1 also describes how the consumption of hydrogen can be reduced by introducing hydrocarbons (e.g., natural gas) into the furnace, when the effect of a vapour reformation of the hydrocarbons is exploited.

The time that the iron powder remains in the furnace is determined, on the one hand, according to its initial and according to the desired end content of oxygen, which is to say according to the required reduction work and, on the other hand, according to the boundary conditions for the reduction, i.e., in particular the piled height of the iron powder, the intensity of the gas exchange, and the reduction temperature. What is important is that the hydrogen that is required for the reduction can pass completely through the loosely piled powder and that the steam (water vapour) that is formed during the reduction can escape from the piled powder and from the furnace atmosphere. Annealing times of one to two hours duration are considered normal. After annealing, the iron powder contains a residual oxygen content of less than 0.2%-wt, for example, and has a soft-annealed structure.

What is disadvantageous in the known iron powder reduction is the fact that the reduction process requires large quantities of energy and is costly with respect to the use of hydrogen. The long hold times reduce furnace throughput. In addition, because of the fact that the primary powder particles bake together, an "iron powder cake" is formed, and this has to be broken up, largely by means of a subsequent grinding process.

It is also known that a direct reduction of iron oxides can take place in a cylindrical rotary kiln. Generally speaking, a cylindrical rotary kiln is understood to be a furnace with a tubular processing chamber that is fired directly and rotates continuously during operation. The material that is used passes through this cylindrical rotary kiln continuously. During the direct reduction of iron oxides, lump ores and iron ore pellets are used as the operating material. When this is done, relatively small proportions of fine material can also be processed at the same time. However, very fine powdered iron ore cannot be used.

In contrast to the rotary kiln furnace, a continuously operating furnace with a rotating cylindrical processing chamber that is directly heated can, generally speaking, be designated as a drum-type rotary furnace.

DE 34 39 717 A1 describes the use of such a drum-type rotary furnace to produce powdered tungsten or molybdenum by calcining ammonium paratungstate or ammonium molybdate, when tungsten oxide or molybdenum oxide are formed. These oxides are then reduced to the corresponding powdered metal with hydrogen. Up to now, the reduction of water-atomized iron powder in a drum-type rotary furnace has not been described. Because of the fact that iron powder (and, in particular, water-atomized iron powder) displays a marked tendency to agglomerate, the practitioner skilled in the art would regard a drum-type rotary furnace as unsuitable for the reduction of iron powder. It would have to be anticipated that the formation of iron clumps (a consequence of the irregular grain form of the powder) would disrupt operation of the furnace in an unacceptable manner and would prevent adequate and even reduction of the powder. In addition, there would be a danger of the constant removal of fine fractions of the iron powder in connection with the required gas exchange needed to renew the furnace atmosphere, and this would lower the yield resulting from the process and would also be prejudicial to the economy of such a process.

It is the task of the present invention to describe a process for the reduction and soft annealing of water-atomized iron powder, which, to a large extent, eliminates the disadvantages described heretofore and which is, in particular, quicker in contrast to former annealing processes and which can be carried out with by using smaller quantities of energy and reduction agent. In addition, an apparatus for carrying out this process is also proposed.

With respect to the process of this kind, this problem has been solved with the characteristic features of the process described herein. Preferred features of the process are also described herein. An apparatus for carrying out the process according to the present invention is described herein, and preferred features of the apparatus are described herein as well.

According to one aspect of the present invention, there is provided a process for the continuous reduction and soft annealing of water-atomized iron powder, the powder particles of which are, at least in part, covered with a layer of oxide, which is carried out in the form of a loose powder charge that is moved through a processing chamber, indirectly heated by a furnace, the processing chamber comprising a heating zone, a reduction zone, and a cooling zone, a reducing atmosphere being maintained in the processing chamber by the constant introduction of reduction gas and by removal of reduction products that are formed thereby, wherein, during its passage through the processing chamber, the powder charge is constantly one or both of mixed and agitated, at least in the reduction zone; furnace temperature within the reduction zone is maintained in the range of 800 to 950°C; and fresh reduction gas is constantly introduced into the reduction zone in order to control the dewpoint of the furnace atmosphere.

According to another aspect of the present invention, there is provided an apparatus for carrying out the process as defined herein comprising a rotary-type drum furnace having a wall and that is heated indirectly, that comprises (i), a processing chamber divided into three zones; a heating zone arranged at a charging end of the drum furnace, a reduction zone arranged in a centre section of the drum furnace, and a cooling zone at an outlet end of the drum furnace, (ii) a reduction gas feedline and an exhaust vapour exhaust line being connected to the processing chamber, there being at least one inlet opening for introduction of fresh reduction gas in the reduction zone, and (iii) one or more mixing structures at least in the reduction zone, each mixing structure being moveable independently of walls of the drum furnace and each of which mixes the iron powder in addition to agitation of the iron powder that is caused by rotation of the processing chamber.

According to still another aspect of the present invention, there is provided the use of the apparatus as described herein for the continuous reduction annealing of water-atomized iron powder that is in the form of a loose powder charge, that is not mixed with powdered or liquid additives.

The essence of the present invention is to be found not only in the fact that it makes provision for the application of a process principle, already known per se for the reduction of other materials, in which the powdered material that is to be processed is constantly agitated, to a water-atomized iron powder. Rather, it first creates the prerequisites for using this principle that, up to now, has appeared to be unuseable on account of the extreme tendency to agglomerate that is displayed by this iron powder, in that, in addition to the intensive mixing of the iron powder, at least in the reduction zone, it simultaneously prescribes restriction of the annealing temperature to direct introduction of fresh reduction gas in order to achieve a measure of local control of the dewpoint in the furnace atmosphere of the reduction zone.

As a rule, in conventional reduction processes, the fresh reduction gas is introduced at the outlet end of the annealing furnace, in counter-flow to the iron powder, whereas the exhaust vapours are drawn off at the charging end of the annealing furnace. When this is done, no attempt is made to influence the furnace atmosphere within the reduction zone. The result of this is that the iron powder particles are brought into contact with reduction gas having a different water content, depending on their level within the immobile pile of iron powder for, as a result of the reduction processes that are taking place, the reduction gas is constantly re-enriched with water vapour and, for this reason, has a dewpoint that rises constantly compared to the original fresh reduction gas. According to the present invention, the dewpoint of the furnace atmosphere can be held locally at the desired level because of the deliberate introduction of fresh reduction gas into the reduction zone. As a result of the constant agitation and mixing of the iron powder, for all practical purposes all of the iron powder particles can come into contact with the reduction gas, the dewpoint of which is at a considerably lower level as measured in the deeper layers of the static pile of powder in conventional annealing processes. Because of this, it is possible to greatly reduce the reduction temperature compared to the prior art known up to now, as a function of material quality, without having to accept disadvantages with respect to the remaining residual oxygen content of the iron powder or the annealing times that are required. The combination of features offered by the present invention leads to the surprising result that the anticipated effect of clumping of the iron powder during annealing could be either prevented or kept at a level at which it is easily managed.

According to the present invention, it is possible to achieve this without the addition of powdered ingredients such as calcium oxide, calcium fluoride, magnesium oxide, sodium carbonate, titanium dioxide, or similar substances to the iron powder that is to be reduced in a drum-type rotary furnace, as is described in DE-C 29 21 786. According to the process described therein, it is not water-atomized iron powder, but rather a reduced (ground) iron oxide powder that is used as the raw material, with 5 to 30%-wt of these powdered ingredients being added in order to prevent the formation of agglomerate. After the reduction has been carried out, these additives have to be separated off once again in an additional stage of the process. In contrast to this, the process according to the present invention is much simpler and more cost-effective.

What has been said above also applies to comparison with the reduction process for metal powder, described in DE-A 27 31 845, which is similarly carried out in a drum-type rotary furnace. In this known process, the metal powder is first mixed with organic substances such as dextroses, starches, organic acids, oils, alcohols, waxes, or greases, and derivatives thereof, and is only reduced after this has been done. When this is done, it is also recommended that, prior to processing in a reduction furnace, the metal powder is formed into pieces, which is to say it is rendered extremely coarse-grained (e.g., 8 mm grain size) by way of a pressing process. In the process according to the present invention such measures, i.e., in particular, the addition of powdered or liquid additives to the iron powder, can be dispensed with.

The present invention will be described in greater detail below on the basis of the diagrams shown in figures 1 to 6. These diagrams show the following:

Figure 1: a longitudinal section through a drum-type rotary furnace according to the present invention;
Figure 2: a cross section on the line A-A in figure 1;
Figures 3 & 4: different structures incorporated into the processing chamber of the drum-type rotary furnace;
Figure 5: a modification of the drum-type rotary furnace in figure 1;
Figure 6: a cross section on the line B-B in figure 5.

The drum-type rotary furnace 1 that is shown in figure 1 and used to reduce water-atomized iron powder is constructed on a supporting framework 14. The core of the drum furnace 1 is the tubular and rotatable drum 2 that surrounds the processing chamber for the iron powder, which is shielded from the external atmosphere. The supporting framework 14 is supported on a first support 15 through a rotating joint with a horizontal axis of rotation and on a second support 16, which is of adjustable height. It is possible to vary the amount of time that the iron powder remains within the drum 2 by selection of the slope and the speed of rotation of the drum 2. For part of its axial length, the drum 2 is surrounded by a multi-layer outer casing 11 that incorporates thermal insulation and which also includes the furnace body (fire vault) that is used to heat the drum 2 indirectly. The cross-sectional drawing at figure 2 shows that the outer casing 11 is divided horizontally, there being a seal 23 in the dividing plane. Heating is effected by one or a plurality of gas or oil burners 19. Fundamentally, it is also possible to use any other source of heat. The exhaust gases that are generated by combustion of the fuel that is used pass to the outside through the exhaust gas connector 13. In order to simplify temperature control along the axis of the drum 2, baffles can be fitted in the furnace vault 12, and these then divide this chamber into a number of sections.

In order that the drum 2 can be driven by a motor it incorporates two drum drivewheels 17 outside the furnace vault 12 and the outer casing 11; these run on the drum drive 18 that is secured to the supporting frame 14 and fitted with rollers. The iron powder that is to be reduced within the drum 2 passes through a powder dispensing system 3 by means of a conveyor system (e.g., a screw conveyor), through the lock 4 that is arranged on the left-hand face side of the drum 2, and into the interior of the drum 2, which is to say into the processing chamber that is divided into three zones. These three zones are the heating zone 5 at the charging end of the furnace, the reduction zone 7 that is adjacent to this, and the cooling zone 8 that is arranged at the outlet end of the furnace.

The zone that immediately follows the lock 4 and is configured as the heating zone 5 extends into the starting area of the heated part of the furnace. The iron powder that has been introduced is heated to reduction temperature (at least approximately 800°C, but a maximum of 950°C) in this heating zone 5. It is advantageous that the heating be carried out as rapidly as possible. It is important that the powder filling is continuously agitated during processing. When this is done, effective mixing must take place at least in the reduction zone 7. This is achieved by the constant rotation of the drum 2, only a relatively small fraction of which is filled. The agitation of the powder filling must be of an intensity at which there is a great deal of friction generated between the particles of the powder. Because of this, and because of the comparatively low furnace temperature, it is possible to reduce or even entirely prevent any clumping of the water-atomized iron powder which, because of its split and irregular grain configuration, displays a very high tendency to form agglomerate. The mixing of the iron powder can be greatly facilitated by means of special structures 6, which are diagrammatically indicated only in figures 1 and 2. As an example, mixer bars 24 (figure 3) that are installed on the inner surface of the drum 2 are particularly well suited for this purpose. However, mixer bar baskets (with or without their own dedicated drive system) that can rotate independently of the drum 2, can also be used. Figure 4 shows such a mixer rail basket 20 diagrammatically; in this, the mixer bars are, for example, tubular.

However, other mixing devices such as screw-type conveyors or helical structures can be used, and these can move either with or against the main direction of movement of the iron powder (as is determined by the direction of rotation of the drum).

Separately-driven structures 6 entail the particular advantage that, to a very large extent, they can prevent the iron powder baking onto the inner casing of the drum 2. In order to remove any such baked-on powder, one or a plurality of strikers can be arranged outside on the casing of the drum 2, and these generate mechanical oscillations in the drum casing at timed intervals as a result of hammer blows.

It is has been found to be particularly advantageous if the drum 2 of the drum furnace 1 incorporates an inner screen-like intermediate layer in the area of its heating zone, this layer facing the processing chamber. Tests have shown that by arranging such a screen-like intermediate layer close to the walls of the drum it is possible to bring about a significant reduction of the baking-on effect of the iron powder that is to be processed to the drum walls, or even prevent this entirely. This also means that to a very large extent the powder particles can also be prevented from clumping together.

The screen-like intermediate layer is preferably formed as a mesh basket 25 that, in a particularly preferred embodiment of the present invention, is connected through a rod 26 that leads out of the drum 2 on the left-hand side to an oscillating or shaker system 27. A conventional oscillating or shaker motor can be used as the oscillator or shaker 27, this being operated periodically in order to vibrate the mesh basket 25 that is arranged within the furnace 1 and thereby provide an additional means of preventing the iron powder from baking onto the walls. The shaking or vibration produces a scraper effect so that any iron powder that is baked on is removed once again. Suitable perforated sheet metal through which the particles of iron powder can easily pass can be used as the screen layer. The mesh size of such perforated sheet metal can, for example, lie in the range of 5 to 15 mm. It is important that the mesh-like intermediate layer ensures sufficient heat transfer to maintain the desired temperature range within the interior of the furnace.

In order to prevent clumping or to ensure the removal of any agglomerates, the iron powder that is to be processed can have pieces of ballast material (e.g., in the form of iron balls) added to it according to a further advantageous development of the present invention; these then have a certain grinding action on the agglomerates and increase the amount of friction between the particles of iron powder. After passing through the drum furnace 1 and separation from the iron powder in a circulatory system, this ballast is returned to the entrance to the drum 2 or else retained within one furnace zone by barriers that only permit passage of the iron powder. Because of the considerably larger particle size compared to the iron powder this separation can be effected very simply and without great expense. As a rule, it is not necessary to add ballast within the framework of the present invention.

Viewed in the direction of movement of the iron powder, the heating zone 5 becomes the actual reduction zone 7, within which there are also structures 6 that enhance the degree of mixing to which the powder is subjected. Various structures 6 can be used in each of the individual sections of the drum 2. Particularly suitable are screws for the entrance area to the heating zone 5 and the starting area of the reduction zone 7, and as mixer bars for the reduction zone 7.

When this is done, more intensive mixing of the iron powder takes place in the areas of the drum furnace that are at higher temperatures than is effected in the areas where the temperature is lower. In the reduction zone 7 because of the slight inclination of the constantly rotating drum 2, the iron powder that migrates slowly through the drum 2 is exposed to a reducing atmosphere, in particular an atmosphere that is generated by the introduction of hydrogen gas, at oven temperatures of at least 800°C. The fresh reduction gas is introduced into the reduction zone 7 at different points that are separated from each other in the axial direction of the drum 2 and is, as far as possible, directed in counter-flow to the direction of movement of the iron powder. This should have the lowest possible dewpoint, in particular a dewpoint of below -60°C. Furthermore, it is preferred that correspondingly more outlets for removing the exhaust vapours from the reduction zone be provided. In this way, in conjunction with the intensive mixing and agitation of the iron powder filling, it is possible to bring the oxide covering of all the iron powder particles which is to be reduced with a reduction gas with a comparatively low dewpoint, even though water vapour is generated constantly because of the reduction processes carried out by means of hydrogen. In contrast to this, reduction conditions that are associated with conventional iron-powder reduction processes that involve immobile iron-powder filling and the introduction of reduction gas from the outlet side and the removal of exhaust vapours from the charging side of the annealing furnace are far less favourable from the very outset.

In order to permit the controlled influencing of the furnace atmosphere, and optionally an improvement of temperature management within the drum 2, it may be useful to arrange baffles in the interior of the drum 2, these dividing the processing chamber, in particular the reduction zone 7, into sections (e.g., two or three) that can be regulated independently of each other and which are so secured as to leave a gap 21 between their periphery and the casing of the drum 2, through which it is possible for the iron powder to move in an axial direction when the drum 2 rotates. The locations for the introduction or removal of the reduction gas or of the exhaust vapours, respectively, must in each instance be so distributed along the axis of the drum as a function of throughput that the dewpoint of the furnace atmosphere can be controlled locally, and thus kept within suitable limits. The downward restriction of the dewpoint is effected for economic reasons, for a lower dewpoint is associated with a rise in the consumption of reduction gas. The reduction gas introduction lines and the exhaust vapour removal lines are not shown in the figures. It is more expedient that these lines be arranged in the area of the longitudinal axis of the drum 2. The consumption of reduction gas can be restricted to a value of 80 to 100 Nm^3/tonne of iron powder when hydrogen is used.

Within the reduction zone 7, which in the case that is illustrated is divided into two areas, which can be individually heated to various levels, by the baffles 22 in the furnace vault 12, the furnace temperature is restricted to a maximum of 950°C. In the case of non-alloy or low-alloyed iron powder it is advantageous to restrict the temperature to a maximum of 900°C, whereas in the case of higher-alloy iron powder it is preferable to use higher oven temperatures of up to 950°C. When this is done, however, the reduction temperature that is used during the procedure according to the present invention is significantly lower (i.e., by approximately 150 to 250°C) compared to the temperature used in conventional iron powder reduction, which is 900 to 1200°C, depending on the level to which the powder is alloyed.

From the mechanical standpoint, the drum-type furnace according to the present invention is so regulated that the length of time during which the iron powder stays in the reduction zone is significantly less than one hour. Useful dwell times amount to 15 to 20 minutes. In this respect, too, the process according to the present invention differs significantly from the previously known processes, in which dwell times of approximately one to two hours are used. Because of these technical measures connected with the process (relatively low reduction temperature, short dwell time, intensive mixing of the powder, a lower dewpoint temperature of the furnace atmosphere), it has been possible to avoid the formation of agglomerates during the reduction process to a very large extent.

The cooling zone 8 follows the reduction zone 7; in this the iron powder that has been reduced is cooled indirectly to a temperature lower than 100°C. The temperature is lowered by using, for example, cooling water, that can then be used, for example, for heating purposes other than in the reduction annealing process. However, it is also possible to use part of the waste heat to pre-heat the fuel, the combustion air, and the reduction gas that are used.

A further lock 9 is arranged at the end of the cooling zone 8 and this permits the continuous removal of the reduced iron powder without affecting the furnace atmosphere in the interior of the drum 2. A powder-removal system 10 that is installed at the lock 9 makes it possible to fill the iron powder into transportation containers without any problems.

The effectiveness of the process according to the present invention will be described in greater detail below on the basis of one embodiment that has been effected in a test furnace.

Molten iron of the following composition (%-wt) was atomized in the usual way by water atomization: 0.01% carbon, 0.03% silicon, remainder iron and the normal impurities.

Essentially, the iron powder that was produced has a grain size in the range of 300 to 400 micrometers (mean grain size 90 micrometers) and had an oxygen content of approximately 0.9 to 1.1%. The grain shape was irregular. After drying, this iron powder was added continuously to the processing chamber of an indirectly heated rotary-type drum oven. The diameter of the drum (processing chamber) amounted to 300 mm. The iron powder filled the cross-sectional area of the drum to approximately 5 to 15%. The heated section of the rotary furnace (heating zone and reduction zone) was divided into three areas that could be heated separately. The furnace temperatures that were set amounted, in the direction of movement of the iron powder, to 850°C, 900°C, or 950°C, respectively. The inside of the drum wall within the area of the heating zone and the reduction zone was fitted with mixer bars.

The inclination of the drum axis towards the outlet end was so adjusted that with the drum rotating at a speed of approximately 1.6 rpm the hold time in the reduction zone amounted to approximately 30 minutes. In the cooling zone that was adjacent to the reduction zone of the drum-type furnace, the iron powder was cooled to approximately 50°C. Pure hydrogen with a dewpoint of approximately -60°C was used as the reduction gas. The consumption of reduction gas amounted to approximately 90 nmyy3/tonne of iron powder. Fuel consumption was approximately 65 nmyy3 of natural gas per tonne of iron powder. The oven operated without any problem. The reduced iron powder had a residual oxygen content of less than 0.17%. For all practical purposes, the powder structure corresponded almost completely to the original grain. Only small quantities of agglomerates were formed. These remained under the maximum size of approximately 20 mm, and could be broken down into primary grain from the water atomization by hand rubbing. Even within the interiors of these small agglomerates, the reduction annealing had taken place without any restriction. The powder produced in this way was extremely amenable to shaping into compressed bodies.

The annealing process according to the present invention entails a number of important advantages. For example, as compared to conventional annealing, the time that the iron powder remains in the reduction furnace can be reduced to approximately one-third of the former value, e.g., in a belt furnace, with the same initial and final oxygen content. This provides for very high throughput for comparatively low plant costs. Furthermore, the short length of time that the iron powder remains in the apparatus reduces specific fuel consumption to a considerable degree, i.e., to approximately half of the former value. In addition, the consumption of reduction gas can be reduced. Overall, these factors result in considerable savings in production costs.

Because of the low reduction temperature, the consolidation of primary powder particles to form large agglomerates, which can usually always be observed during conventional annealing processes, was hardly seen; any agglomerates that were formed could be broken down to their original primary particles by the application of only a little force, without destroying their structure. Subsequent grinding was always required after conventional annealing and, in addition to the extra costs that this entailed, this also entailed the disadvantage that it resulted in iron powder particles that were of a different structure than the original particle structure. In contrast to this, the process according to the present invention produces a powder, the screening characteristics of which almost completely match those of the original powder.

Most surprisingly, almost no iron dust was lost as a result of the gas exchange in the furnace atmosphere during the process according to the present invention, even though the iron powder that was processed is of an extremely fine grain size. A further important advantage is the fact that the process according to the present invention permits fully continuous and fully automated operation between the material supply bunker and the removal into transport containers, with complete isolation from the atmosphere being ensured. The pan management that is required to move the iron powder in rolling hearth or walking beam furnaces, and the requirement for conveyor belts in belt ovens, is completely eliminated, so that the present invention results in considerable savings with respect to handling and repair costs. Because of the high level of effectiveness of the process, the space required for the plant according to the present invention is considerably smaller than has formerly been the case relative to throughput. Because of the constant movement of the powder charge during the annealing process it is possible to produce an extremely homogenous product at a constantly high level.

In contrast to conventional annealing furnaces, the process can be effected more easily and more deliberately in a rotary-type drum furnace. Because of the fact that plant wear is greatly reduced because of the lower reduction temperature and the complete elimination of parts that are particularly vulnerable to wear, the overall plant is subject to shorter downtime and requires drastically reduced maintenance and repair costs.

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CLAIMS:

1. A process for the continuous reduction and soft annealing of water-atomized iron powder, the powder particles of which are, at least in part, covered with a layer of oxide, which is carried out in the form of a loose powder charge that is moved through a processing chamber, indirectly heated by a furnace, the processing chamber comprising a heating zone, a reduction zone, and a cooling zone, a reducing atmosphere being maintained in the processing chamber by the constant introduction of reduction gas and by removal of reduction products that are formed thereby, wherein, during its passage through the processing chamber, the powder charge is constantly one or both of mixed and agitated, at least in the reduction zone; furnace temperature within the reduction zone is maintained in the range of 800 to 950°C; and fresh reduction gas is constantly introduced into the reduction zone in order to control the furnace atmosphere's dewpoint.

2. The process of claim 1, wherein the reduction products are exhaust vapours.

3. The process of claim 2, wherein the exhaust vapours are steam and carbon dioxide.

4. The process according to claim 2 or 3, wherein the exhaust vapours are discharged to outside of the processing chamber from at least one point within the reduction zone.

5. The process according to any one of claims 1 to 4, wherein the introduction of reduction gas into the reduction zone is effected at a plurality of locations that are spaced apart from each other in an axial direction.

6. The process according to any one of claims 1 to 5, wherein one or both of agitation and mixing of the iron powder is effected by rotation of the processing chamber.

7. The process according to any one of claims 1 to 6, wherein the furnace temperature in the reduction zone is held below 900°C during the processing of a low-alloy iron powder.

8. The process according to any one of claims 1 to 7, wherein the dewpoint of the reduction gas that is introduced into the reduction zone lies at or below minus 60°C.

9. The process according to any one of claims 1 to 8, wherein the mixing of the iron powder in an area of the heating zone's end and at least in an area of the reduction zone's beginning is intensified in comparison to the remaining part of the processing chamber.

10. The process according to any one of claims 6 to 9, wherein the mixing of the iron powder is effected by mixers that operate independently of the rotation of the processing chamber.

11. The process according to any one of claims 1 to 10, wherein friction between the particles of iron powder is increased during either or both of agitation and mixing by adding pieces of ballast.

12. The process according to claim 11, wherein the added pieces of ballast are in the form of iron balls.

13. The process according to any one of claims 1 to 12, wherein hydrogen is used as the reduction gas, the introduction of the hydrogen being restricted to approximately 80 to 100 Nm^3/tonne of iron powder.

14. The process according to any one of claims 1 to 13, wherein the iron powder remains in the reduction zone approximately 15 to 20 minutes.

15. An apparatus for carrying out the process as defined in any one of claims 1 to 14 comprising a rotary-type drum furnace having a wall and that is heated indirectly, comprising: (i) a processing chamber divided into three zones; a heating zone arranged at a charging end of the drum furnace, a reduction zone arranged in a centre section of the drum furnace, and a cooling zone at an outlet end of the drum furnace, (ii) a reduction gas feedline and an exhaust vapour exhaust line being connected to the processing chamber, there being at least one inlet opening for introduction of fresh reduction gas in the reduction zone, and (iii) one or more mixing structures, at least in the reduction zone, each mixing structure being moveable independently of walls of the drum furnace and each of which mixes iron powder in addition to agitation of iron powder that is caused by rotation of the processing chamber.

16. The apparatus according to claim 15, wherein at least some of the mixing structures are configured as a mixing basket that can be rotated independently of the wall of the processing chamber.

17. The apparatus according to claim 15 or 16, wherein a screw is fitted at an input end of the heating zone as the one or more mixing structures.

18. The apparatus according to any one of claims 15 to 17, wherein each of the mixings structures is moveable independently of the other mixing structures, where more than one mixing structure is present.

19. The apparatus according to claim 18, wherein the mixing structures can be driven counter to the rotation direction of the processing chamber.

20. The apparatus according to any one of claims 15 to 19, wherein one or a plurality of strikers that are used to remove any baked-on iron powder from an inner surface of the wall of the drum furnace is or are fitted externally on the wall of the processing chamber.

21. The apparatus according to any one of claims 15 to 20, wherein a screen-like intermediate layer is arranged in the heating zone.

22. The apparatus according to claim 21, wherein the screen-like intermediate layer is in the form of a mesh basket.

23. The apparatus according to claim 22, wherein the mesh basket is connected to an oscillating or shaker system through a linkage that leads out of the processing chamber.

24. The apparatus according to any one of claims 15 to 23, wherein within the reduction zone there is a plurality of inlet openings for the introduction of fresh reduction gas, these being spaced apart in the longitudinal direction of the drum furnace.

25. The apparatus according to any one of claims 15 to 24 further comprising at least one exhaust vapour withdrawal line for the direct removal of exhaust vapours from the reduction zone.

26. The apparatus according to claim 25, comprising a plurality of the exhaust vapour withdrawal lines, each being spaced from an adjacent line in the longitudinal direction

27. The apparatus according to any one of claims 15 to 26, wherein the reduction zone is divided into sections that can be separately regulated with reference to one or both of temperature and atmosphere management by sheet metal baffles that are incorporated transversely to the longitudinal axis of the processing chamber, space being left for a passageway for the iron powder charge.

28. The apparatus according to claim 27, wherein the reduction zone is divided into at least three sections.

29. The apparatus according to any one of claims 15 to 28, wherein the drum furnace's longitudinal axis is inclined, the inclination of said drum furnace being adjustable.

30. A use of the apparatus according to any one of claims 15 to 29 for continuous reduction annealing of water-atomized iron powder that is in a form of a loose powder charge, that is not mixed with powdered or liquid additives.

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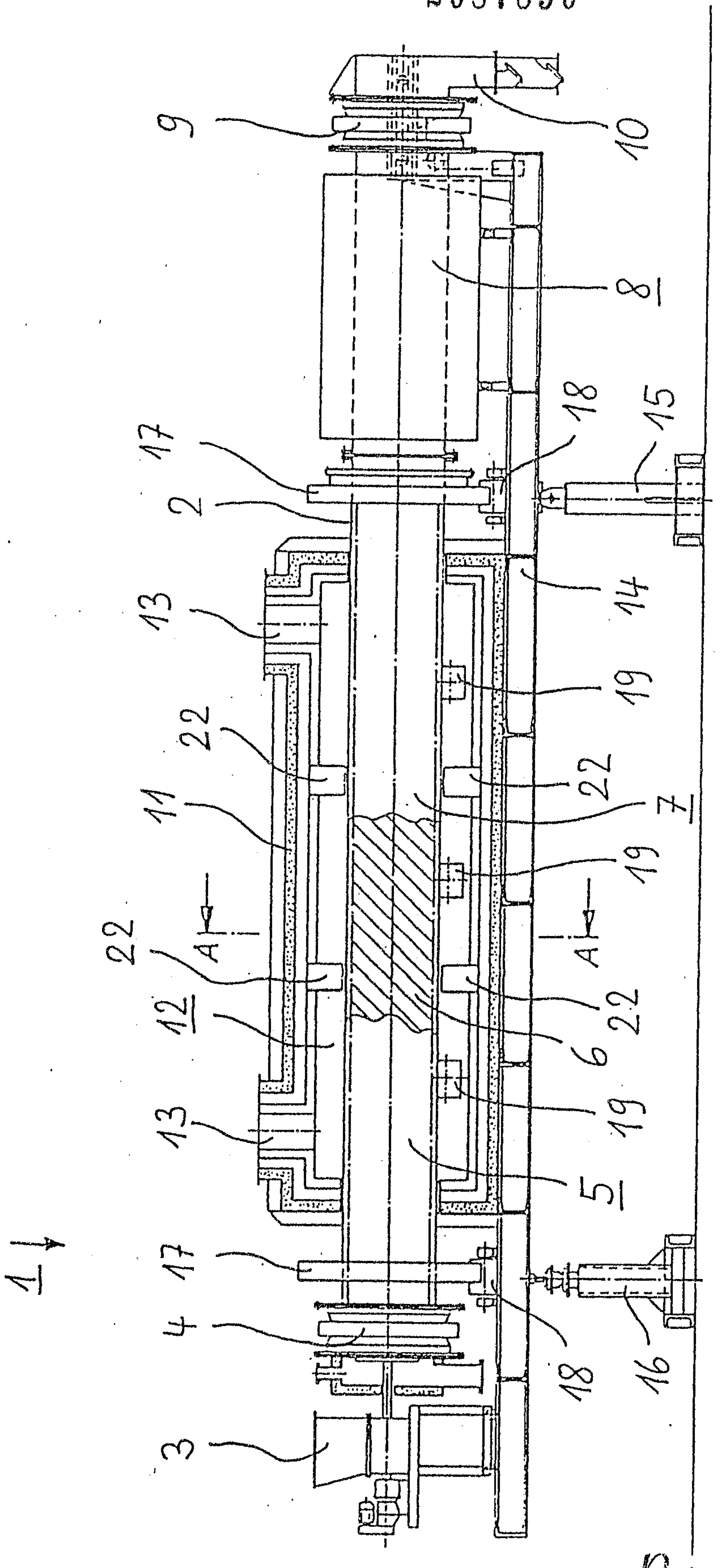

Fig. 1

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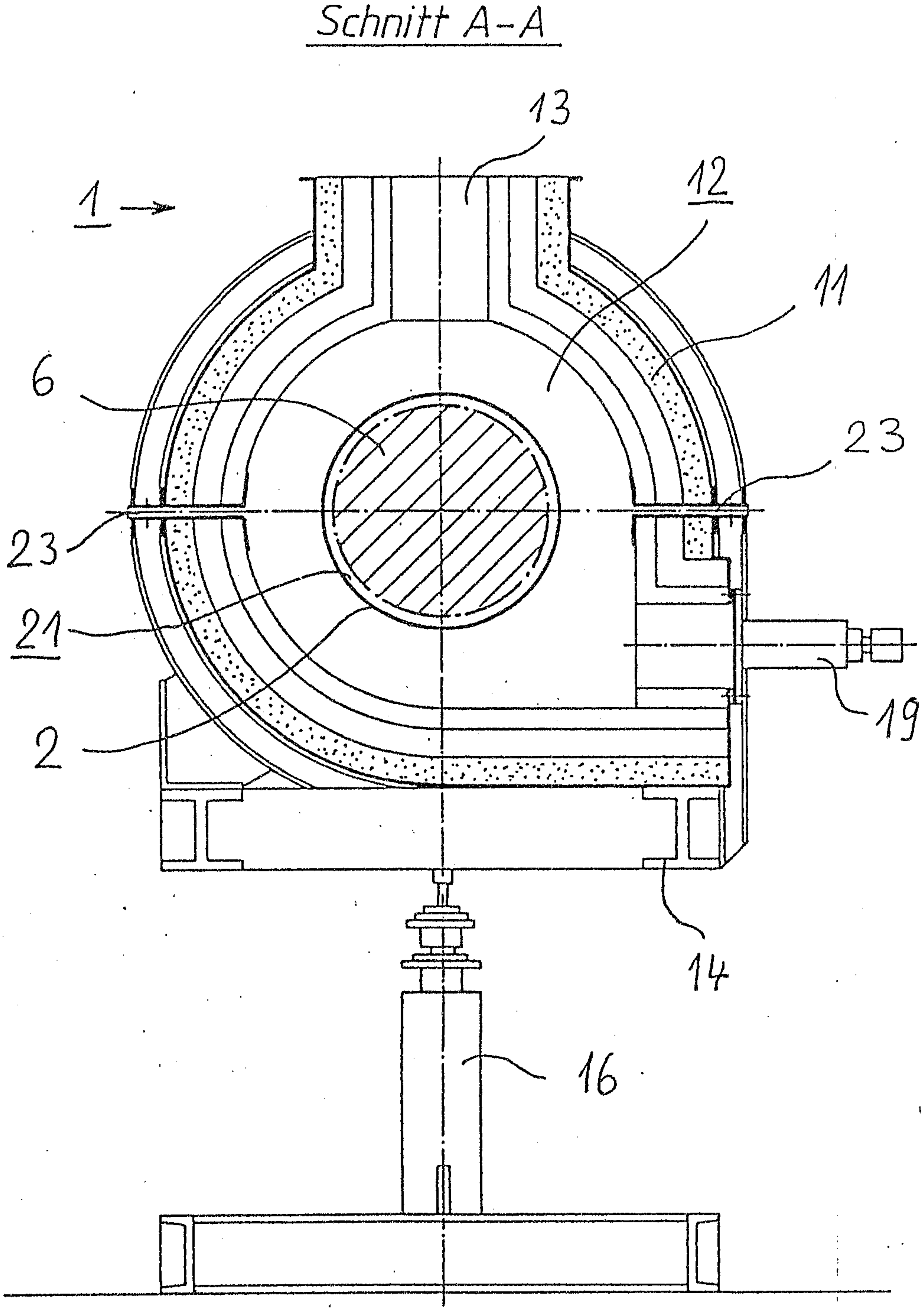

Fig. 2

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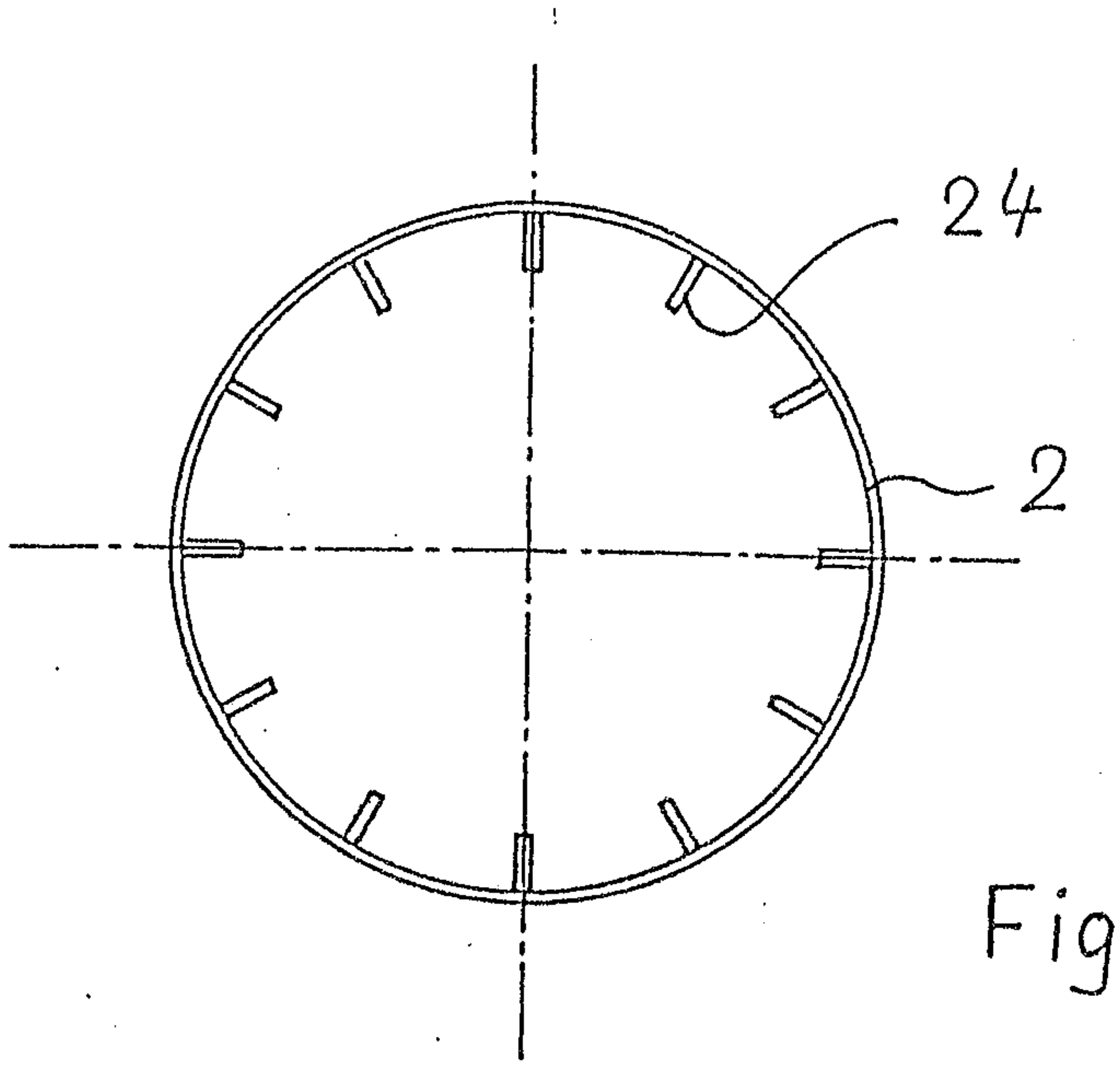

Fig. 3

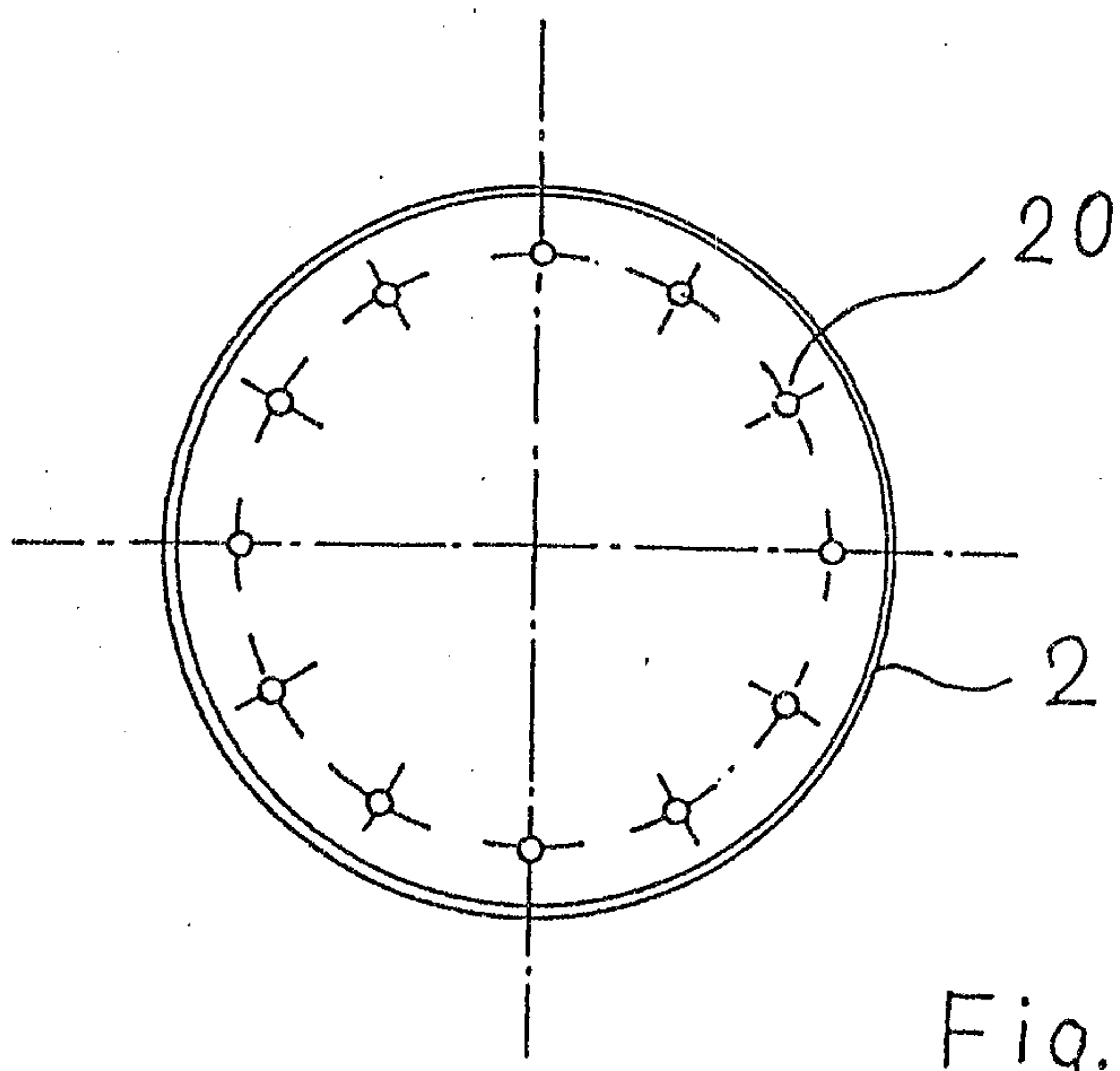

Fig. 4

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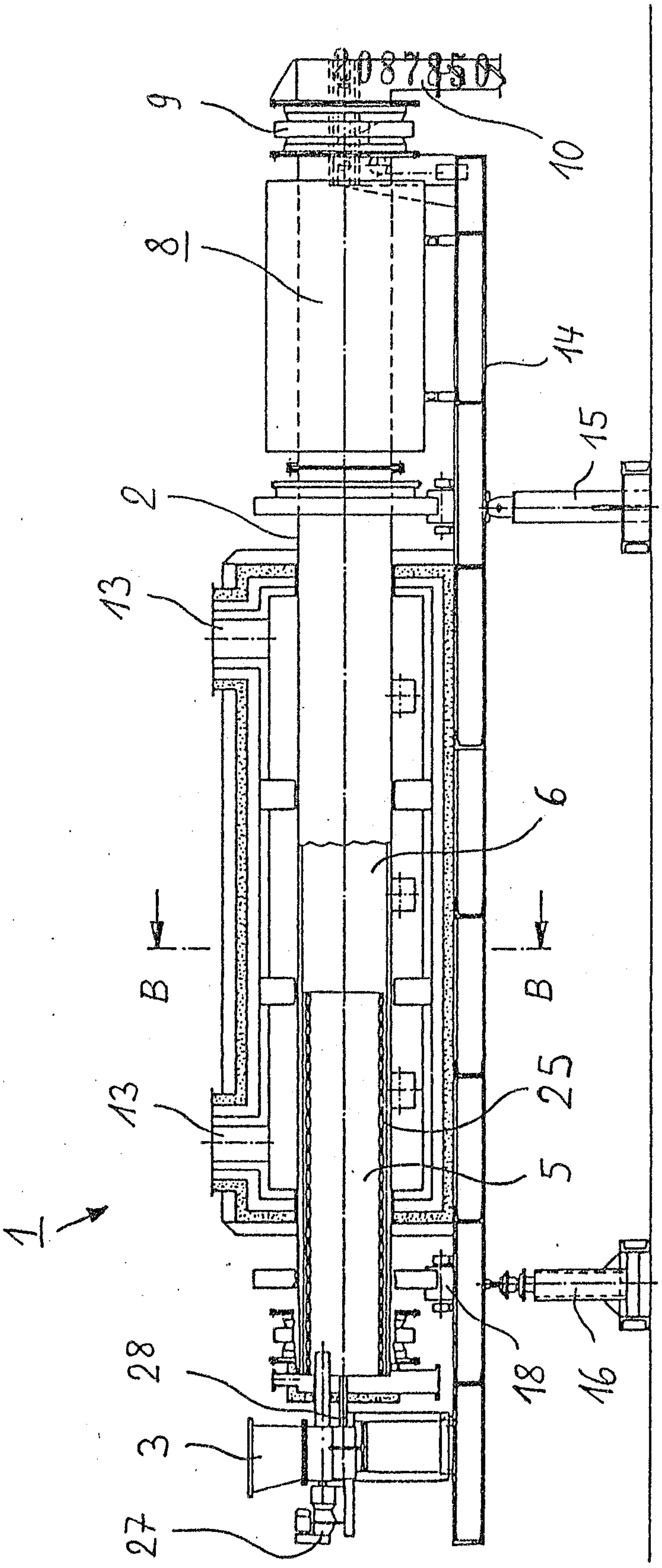

Fig. 5

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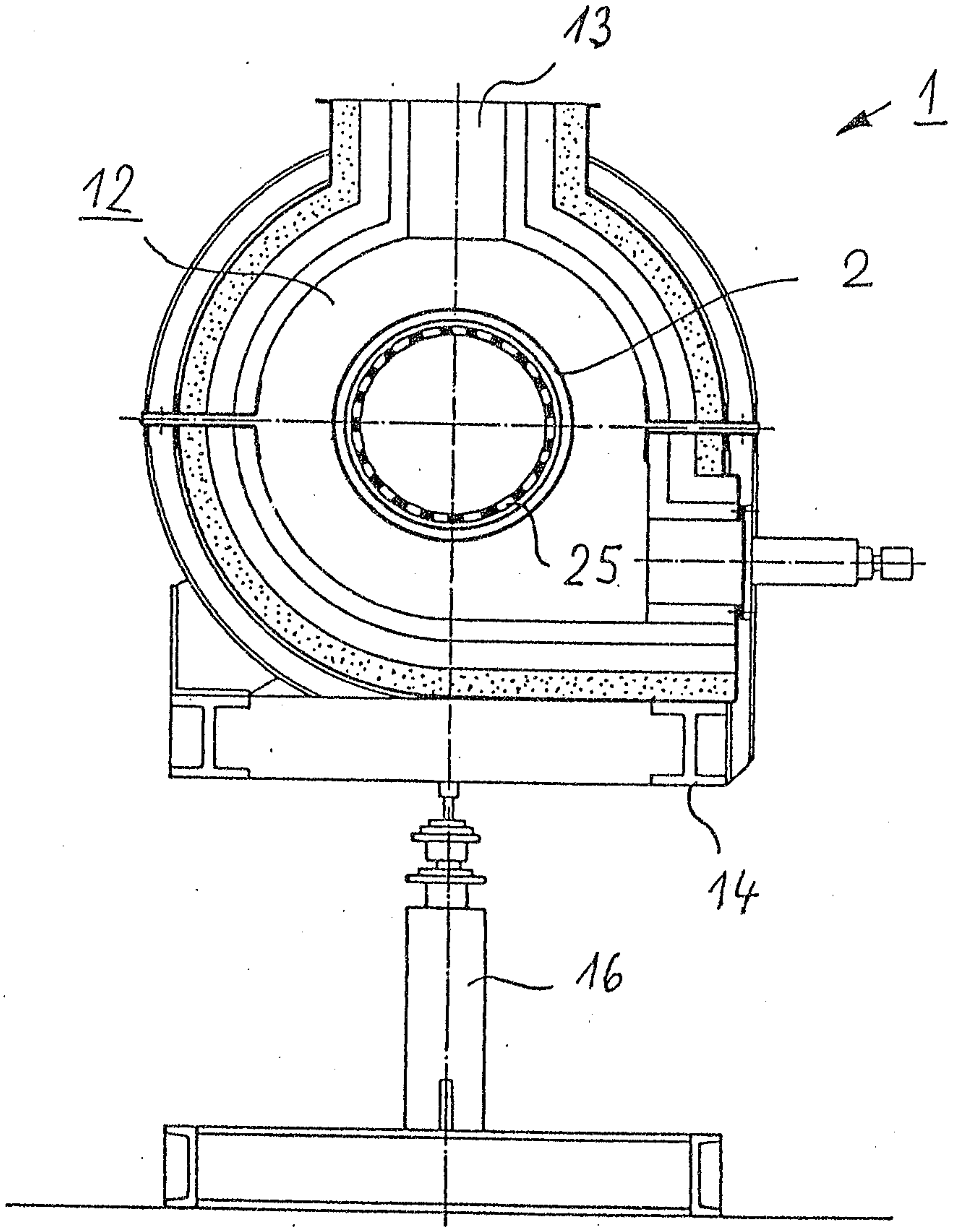

Fig. 6

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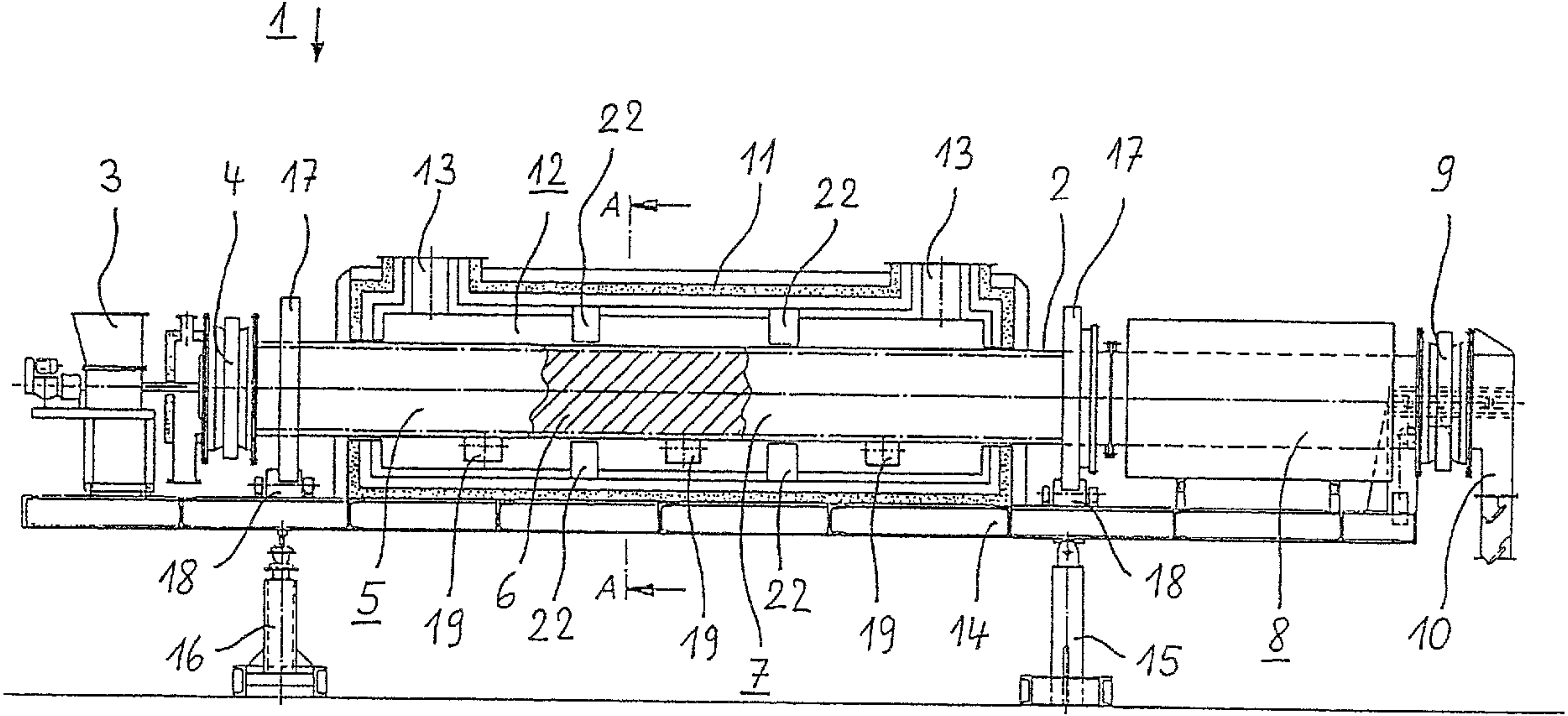
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